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ROOT KNOT IN ARIZONA

By J. G. Brown

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ROOT KNOT IN ARIZONA

By J. G. Brown

INTRODUCTION

Root knot caused by the common nematode (*Heterodera marioni*) is a worse menace to agriculture in Arizona than any other disease of plants. Infestation is gradually spreading in various ways to hitherto clean soil. Nematode-infested plants are sold by nurseries to unsuspecting or indifferent customers. Unrestricted exchange of noninspected plants among gardeners is an important means of introducing nematodes into clean soil. Tractors and other farm implements are moved from nematode-infested fields to clean fields without removal of the soil masses that they may carry and subsequent cleaning. Infested peelings from potatoes, carrots, and other vegetables that are sold in the market reach soil in manure and in other ways. By these and other processes of infestation, all more or less preventable, the originally nematode-free soils of Arizona are losing in agricultural value.

Root knot cannot be cured. Because the common nematode can feed on more than 1,288[1] different kinds of plants, including important garden, truck, orchard and field crops as well as many ornamentals, shade plants and weeds, the parasite is difficult or impossible to starve out of infested soil. Few, if any, of the immune crop plants available for use in starving nematodes pay nearly so well as susceptible crops customarily grown in the state on nematode-free soil, therefore the operators of farms hesitate to exchange the growing of a "money crop" for the nematode-resistant crop until they are forced to do so by the ravages of disease. Furthermore, only temporary reduction in loss results from the growing of root-knot resistant rather than immune crops, for the root-knot disease again appears when susceptible crops are returned to the soil.

Eradication of nematodes, either by the use of immune crops or by fallowing is uncertain and may require long periods of time. The cost of chemical disinfestation of the soil has made that method more or less impractical for large acreages. Even in such small infested areas as city lots and home gardens where the cost is not prohibitive, disinfestation of the soil often involves the removal or destruction of valuable noninfested as well as infested trees and shrubs and thus discourages the owner from applying the necessary treatment. Yet prevention of root knot is most desirable and eradication of infestation should be attempted wherever feasible; in fact, the latter has already started (Plate I). Both prevention and eradication of root knot primarily involve the recognition of the symptoms.

[1] Cox, C. E. and Jeffers, W. F., "Root Knot." *Univ. of Maryland Ext. Serv. Bul. 113.* Mar., 1946.

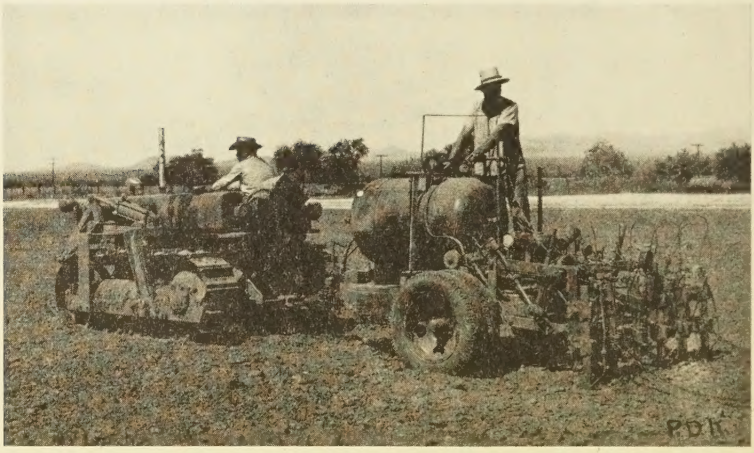

Plate 1.—Chemical treatment of the soil of a large Arizona field for control of the root-knot nematode.

SYMPTOMS OF ROOT KNOT

There is just one dependable symptom for diagnosing root knot. That symptom is galls on the roots. The knots vary in shape (Plates II, III, IV, VI, VIII, IX, XII, XIII, XV, XVI, XVIII) from roundish to elongate, and in size from galls barely visible to those as large or larger than a walnut, although exceptional galls up to approximately two feet in diameter have been reported.[2] The appearance and size of the knots vary with the time since nematodes entered the root, kind of plant (Plates II, III, XIII, XV) and its susceptibility, prevailing temperatures, and other factors.

Root knots should be looked for on at least three sides of large suspected plants. Infested trees (Plates IX, XVI, XVII, XVIII) and large shrubs often show knots on fine roots a foot or two from the base of the trunk. In other cases the knots are farther out. Sometimes the small knots may more readily be detected by the sense of touch rather than sight. Infested rootlets drawn between the thumb and forefinger often feel irregular in thickness when the thickenings are still difficult to see.

WHAT KNOTS ARE

Knots or galls on the roots of plants attacked by the common nematode at first consist of soft tissues. Those tissues are made up of living units (cells) that are thin-walled and can increase in number and size. In some way, probably by the saliva excreted

[2] Steiner, G.; Buhrer, Edna M.; Rhoads, Arthur S., "Giant galls caused by the root-knot nematode." *Phytopathology 24:* 161-163, 1934.

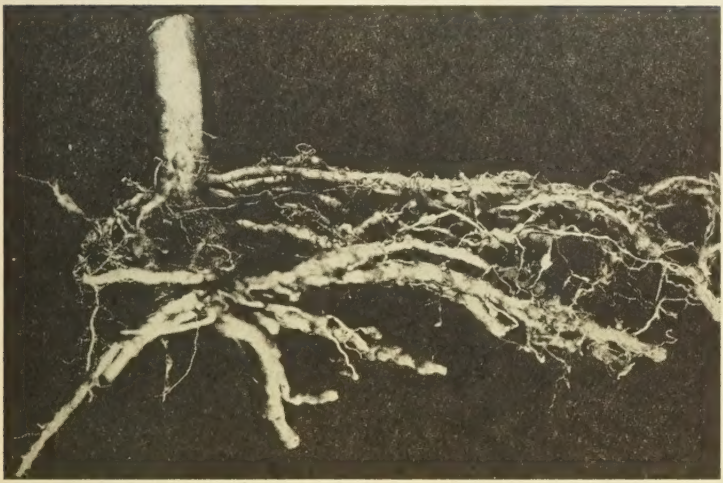

Plate II.—Root knot on tomato plant.

by the nematodes in the root, the soft-tissue cells are stimulated and proceed to enlarge and multiply. These cells about the parasite may then differ in structure from the same kind of cell in healthy tissues. Usually, the enlarged (giant) cells (Fig. 1) contain more than the normally single, central governing body (nucleus). Other soft-tissue cells may elongate, thicken their walls, and become wood cells. Wood cells surrounding a nematode in the soft tissues of the infested part may cause the death of the parasite.[3] The described increase in size of cells results in a local swelling, the gall or knot, that may finally break open. From the ruptured gall escape numerous nematodes that may spread the infestation by entering tender underground parts of the same or another plant. The facts just set forth have important practical significance: formation of knots is really growth and, as such, uses up food material and energy that should go into the building of useful plant parts rather than useless or harmful ones; frequently, the life of nematode-infested plants, particularly perennials, may be prolonged by generous artificial feeding through the soil (manuring) and, on the other hand, death may come quickly to infested plants in sterile soil; the formation of protective wood cells affords a hint to the breeders of nematode-resistant plants; rupture of "ripe" galls, liberating large numbers of nematodes into the soil, must be anticipated in the practice of using so-called "trap" crops (page 39).

[3] Colla, Ada Silvia, "El aparato radicular de algunas formas de *Nicotiana tabacum* en relacion con los ataques de *Heterodera marioni* Cobb." *Arch. de Biol. Veg. 1:* 33-60, 1943.

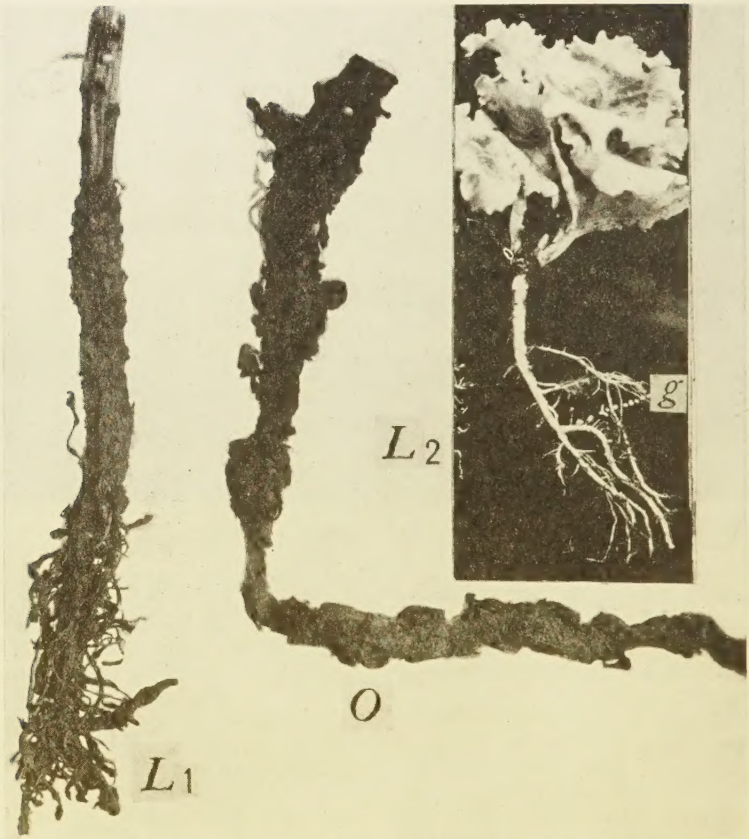

Plate III.—Root knot on mature lettuce root, L_1, on young lettuce roots, L_2 (small galls at g), and on okra root, O; accompanied by Texas root rot on L_1 and O from fields in Arizona.

WHERE ROOT KNOTS FORM

The knots usually start at or near the tender ends of roots and rootlets. The affected part may or may not be killed. Frequently the growing point of the root again pushes forward from the gall, the newly formed piece of root becomes infested in turn and a new gall results. Repetition of the processes of elongated growth, infestation, and gall formation often gives to the root the appearance of a string of beads.

Knots induced in plants by the common nematode, although much more widespread on roots, also occasionally occur on stems. For example, tubers of the potato plant that are really under-

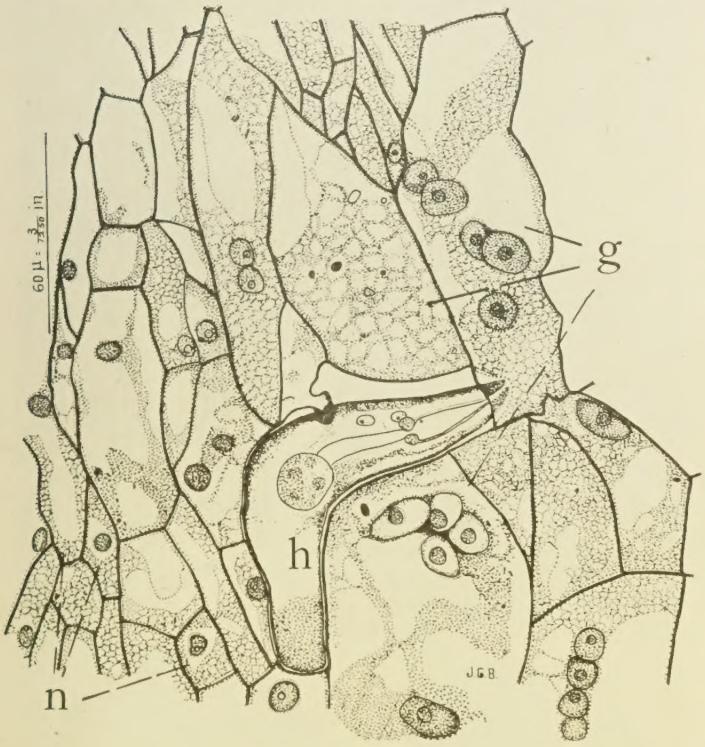

Figure 1.—Drawing of a small piece of a thin slice through a nematode gall on cowpea rootlet; (g) giant cells of gall; (h) head of nematode worm (back part of body cut off); (n) normal-sized cells of rootlet.

ground stems, as well as the roots of that plant, may become parasitized (Plate IV). Indeed, the tubers may be even more favorable for nematode attack than the roots. Cunningham[4] found that the tubers may harbor three generations of nematodes per season in Long Island whereas only one generation per season developed in the roots. The largest nematode galls yet to be described[5], nearly 2 feet in diameter, were found on the basal stems

[4] Cunningham, H. S., "The root-knot nematode *(Heterodera marioni)* in relation to the potato industry on Long Island." *N.Y. (Geneva) Agr. Exp. Sta. Bul. 667,* 1936.

[5] Steiner, G.; Buhrer, Edna M.; Rhoads, Arthur S., "Giant galls caused by the root-knot nematode." *Phytopathology 24:* 161-63, 1934.

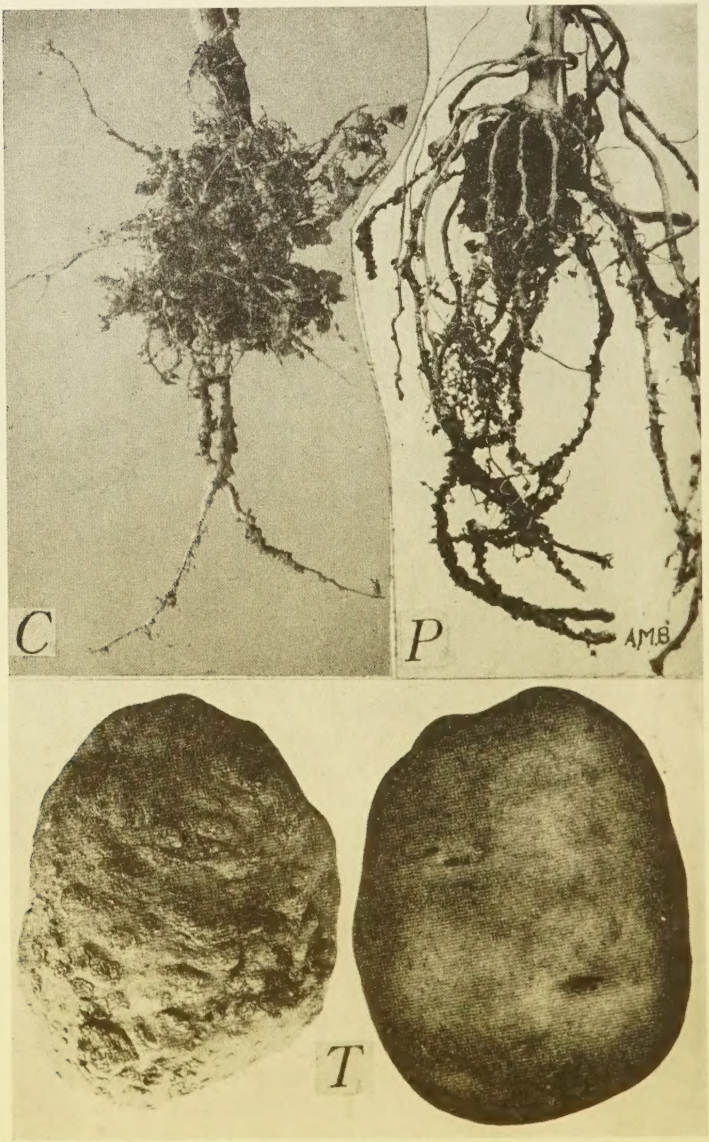

Plate IV.—Root knot on cabbage (C), potato roots (P) and potato tuber (T); healthy tuber at right is same variety as diseased one.
Photos C and P original; T after Cunningham.

of Thunbergia and rhubarb. Nematode stem-galls on tobacco, Impatiens, Cucurbita, and Begonia have been noted.[6]

ROOT ENLARGEMENTS THAT MAY BE MISTAKEN FOR ROOT KNOT

Root knot may be confused with galls caused by the crown-gall bacterium (*Agrobacterium tumefaciens*). In general, root knots are smaller than the bacterial galls (Plate V). Root knots may also be mistaken for beneficial bacterial nodules on the roots of pod-bearing and a very few other plants. Unlike the nodules (Plate VI) that form on the side of the rootlet, nematode galls are in the rootlet. Root knot can be distinguished from woolly-aphis galls (Plate X), occasionally present in our apple orchards, by the white woolly insects on the surface of the latter. Another gall-like condition that may be mistaken for root knot is the deformation (Plate V) of roots that are forced by growth into cracks and crevices in caliche, the hardpan that underlies the soil in places in the Southwest. Portions of roots thus restricted may assume the shape of the space in which they are enclosed.

HOW ROOT KNOT AFFECTS PLANTS

Root-knotted plants are often stunted (Plate VII). Knots may interfere with the water supply of the plant by killing the feeding roots or otherwise changing their water-absorbing and water-carrying capacity. Water is necessary for the swelling that is followed by fixed enlargement of plant units (cells). Total increase in size and numbers of cells makes up what is called plant growth. By interfering with water intake and conduction, root knot seriously slows or stops the growth of the infested plant.

Water and nutrients that are taken in by the plant must be appropriately used if profitable growth is to result. Instead, the plant is stimulated to build locally many extra units by the nematodes in the roots and other infested parts. Some of the units, giant cells (Plate V) are many times the size of the same kind of unit in the same kind but healthy tissues. Both water and nutrients are thus wasted by nematode-infested plants in building knots with materials that should go into useful parts such as fruits (figs, peach and other orchard trees, grape), leaves (lettuce and other salad plants), fleshy roots, tubers and bulbs (beet, potato, onion).

Knotted feeding roots frequently die and decay (Plates VIII, IX). When death of the feeders is extensive, the plant is left with only the larger roots. Although these larger roots are well adapted for transporting water and materials dissolved in it, they are useless for absorbing those substances from the soil, for they are covered with water proofing (corky material) that also excludes substances dissolved in the soil water. Upon the death of the

[6] Colla, A. S.; Franchini, J.; Dolce, G., "Algunos casos de anguilulosis en tallos de plantas cultivadas." *Archivo de Biol. Veg. 1*: 61-63, 1943.

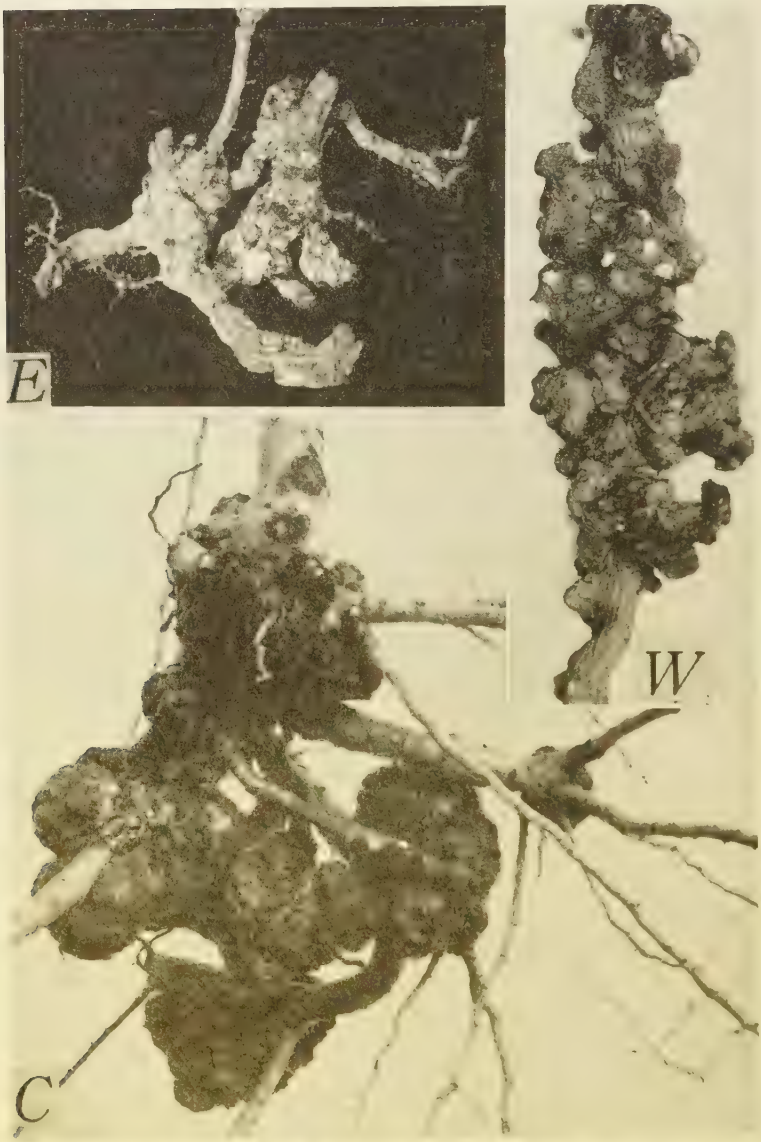

Plate V.—Swellings of roots that might be mistaken for nematode root knot. (E) Enlargement corresponding to cavities in caliche hardpan in which the roots (Washington palm) grew. (C) Crown gall, here shown on peach, but that affects many other plants. (W) Woolly-aphis gall on apple.

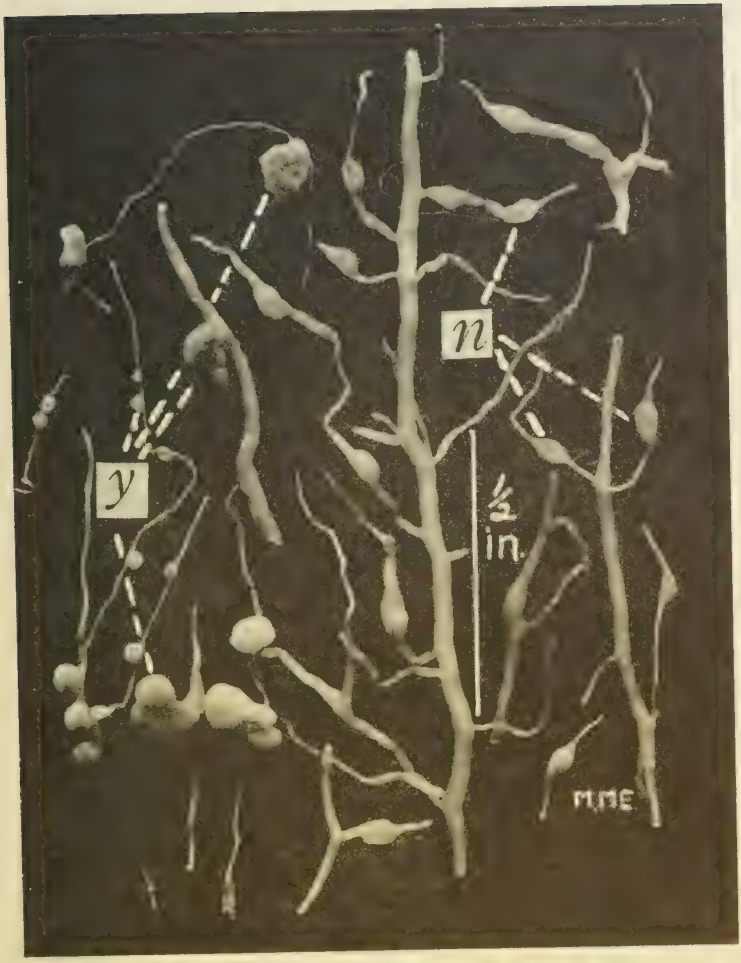

Plate VI.—Pod-bearing plants have beneficial bacterial nodules (y) on the sides of the rootlets. Nematode or root-knot galls (n) are inside the rootlet.

feeding roots, the infested plant is first slowed in growth; later it may be killed.

Nematode-infested plants may show not only dwarfing but also paleness or yellowing of the foliage. The foliage of such plants may be attacked by various spot-producing organisms that would be insignificant or of minor importance with healthy plants. Nem-

Plate VII.—Dwarfing and yellowing of squash plants in the foreground and vacant spaces in the row caused by root knot.

atode attack also makes easy invasion of the roots by other soil-dwelling parasites, for example, cantaloupes by the wilt fungus (*Fusarium bulbigenum*) and solanaceous hosts by the brown-rot bacterium (*Phytomonas solanacera*). Root knot associated with the fungus of southern blight (Plate XI) has destroyed fields of cotton in the Salt River Valley. The indirect action of the common nematode in paving the way for invasion by other parasites has been considered[7] even more important than the direct results of its attack.

SELECTION OF FOOD PLANTS BY THE ROOT-KNOT NEMATODE

Plants are not equally attractive to the root-knot nematode which exhibits various degrees of preference in its choice of food.

[7] Smith, E. F., "A conspectus of bacterial diseases of plants." *Ann. Mo. Bot. Gard. 2:* 377-401, 1915.

Plate VIII.—Root knot on *Lippia canescans* frequently planted for lawns. The disease is often brought to the home lot on rooted cuttings of the plant.

Plate IX.- Washington palms (*Washingtonia filifera*) (A) killed by root knot; note drooping leaves that are browning at the top of the palms. Root (B) from same showing various forms of knots (f) and a branch root (l) virtually deprived of feeding rootlets by the disease.

In general, the same kind of plant is selected that the parents of the nematode attacked,[8] although, if that plant is not available, the parasite may more or less gradually adapt itself to some other species.

RELATION OF VARIOUS PLANTS TO THE ROOT-KNOT NEMATODE

The attacked plant may respond in a widely different manner at different times and in different places. Rapidity and degree of response of the affected plant are influenced by surrounding conditions such as temperature, moisture, cultivation and fertility of the soil, and involvement with other diseases. Severity of attack also varies with the extent and activity of the nematode population which, in turn, is influenced by prevailing soil temperature and moisture, length of infestation period, and presence and numbers of nematode enemies.

Plants are classified in the following pages according to the severity, mildness or lack of symptoms that they may show when they are growing in nematode-infested soil. As very susceptible are listed plants most injured by root knot, and the successive headings below indicate plants with less marked injury, excepting tolerant and immune classes. Tolerant plants are those that produce in infested soil as well as the same kind of plant growing in clean soil, in spite of the presence of root knots. Immune plants show neither root galls nor other symptoms of nematode attack, even in heavily infested soil.

Plate X.—Freesias damaged by the root-knot nematode. Note small galls (g) and discolored (yellowing) leaves.

[8] Steiner, G., "The problems of host selection and host specialization of certain plant-infesting nemas and its application in the study of nemic pests." *Phytopathology 15*: 499-534, 1925.

Plate XI.—Root knot associated with southern sclerotial blight (*Sclerotium rolfsii*) caused thinning and dwarfing of the stand of Acala cotton in the area around the farmer in the middle ground. The photograph was taken after leaf-fall in order to show stalks and branches.

RELATION OF VARIOUS PLANTS TO THE ROOT-KNOT NEMATODE[9]

VERY SUSCEPTIBLE

Ageratum
Arctotis, bushy
Banana
Bean, mung
Calendula
Cantaloupe
Dahlia
Daisy, gerbera
Fig, common
Garden beet
Gram, red
Hibiscus
Laceflower, blue
Lettuce, garden
Lily, easter
Marigold, pot
Molten fire (Amaranthus)
Nectarine
Palm, fan
Pea
Pigeon pea, red gram
Potato, sweet
var. Nancy Hall
Red Bermuda
Red Brazil
Privet, California
Snapdragon
Squash
Sugar beet
Sunflower, common (some vars.)
Tomato

SUSCEPTIBLE

Alfalfa
Almond
Aloe
Amaranth, spiny
Amaranth, globe
Apricot (on peach root)
Asparagus
Bean, common
Bean, hyacinth
Bean, kudzu
Bean, lima
Bean, soya, vars. Otootan, Biloxi
Blackberry
Broccoli
Cabbage
Calla
Camellia, common
Candytuft, common
Candytuft, annual
Canna, common
Caraway
Carnation
[10]Carrot
Centaurea, cornflower
Chinaberry
Clematis
Clover, white sweet
Clover, Dutch
Cotton
Cress, garden
Cucumber

[9] Mostly compiled from *U.S.D.A. Publication 406* but modified by local records.
[10] See next page.

Date palm
Delphinium
Dewberry
Dianthus, pink, carnation
Dichondra
Flax
Garlic
Geranium, common
Grape, Thompson's seedless
Grass, Chinese crab
Grass, crab
Grass, smooth crab
Hound's tongue
Houseleek, roof
Honeysuckle, Japanese
Iris
Jackbean
Lambsquarter
Larkspur
Lespedeza, perennial
Magnolia, southern
Marguerite
Nasturtium, common
Oak, seedlings
Okra
Palm, date
Palm, Washington
Pansy
Pea (Dolichos), catjang
Peach, Chinese wild
Peach, purple leaf
Pear, common
Paeony
Pepper
Periwinkle
Petunia, common
Phlox, Drummond
Pine, seedlings
Pink
Plum, Bokhara
Poinsettia
Poppy, California
Potato
Pyracantha
Raspberry
Rice
Rice, jungle
Rose, most species
Rutabaga
Scabiosa, sweet
Soybean, some varieties
Strawberry
Sugarcane
Verbesina
Watermelon
Zinnia

TOLERANT

Agave
Artichoke
Cactus, prickly pear
Carob
Catalpa
Century plant
Chive
Clock vine
Collards
Commelina
Cosmos, common
Echeveria
Figmarigold
Grape, fox
Kale
Mulberry
Nasturtium, bush
Pomegranate
Prickly pear
Quince
Sesbania
Strawflower
Sunflower, common (some vars.)
Sunflower, cucumber leaf
Turnip
Vetch
Vetch, Purple
Vetch, Scarlet
Wandering Jew

RESISTANT

Apple
Apricot (on own root)
Aster
Barley
Bean, Castor
Bean, lima, strains Hopi 155, 59922, 5987, 5988, 5989
Calliopsis
Careless weed
Castorbean
Corn, Indian
Day lily
Evening Primrose
Four-o-clock
Geranium, ivy leaf
Grape, Champin
Grape, river bank
Grass, Barnyard
Grass, Sudan
Guar
Lantana, common
Lespedeza
Loquat
Lily, day
Lupine
Marigold, African
Marigold, French
Mesquite
Millet, Eleusine
Millet, (Setaria), African
Mustard, potherb
Nectarine, vars. Lippiatt, late orange, Togatch, Moneck
Onion
Palo Verde
Peach, Australian saucer, Bell October, Lewkins honey, Smith
Sutter Creek
Peanut
Pecan
Persimmon, common
Persimmon, oriental
Pine, seedlings (some spp.)
Plum, Chickasaw
Plum, Damson
Plum, Myrobalan
Plum, wild goose
Potato, sweet, vars. Big Stem Jersey, Creola, Dixie Yam, Enormous, New Gem, Old Long Red, Shanghai, Triumph, Yellow Yam
Potherb Mustard
Privet, Quihou

[10] Nantes variety said to be only slightly malformed by root knot but severely defoliated by blights; Goldmhart slightly malformed by root knot and slightly affected by blights; Chantenay, Model slightly malformed by root knot and slightly affected by blights. Wilson, J. D., *Ohio Bi-Monthly Bulletin 31*: 35-39. March-April 1946.

Rudbeckia
Safflower
Sage, blue
Sage, scarlet
Sesame
Spider, flower
Spurge, upright, spotted
Statice, notch leaf
Stock
Sweet alyssum
Sweet William
Tobacco, common
Tobacco, tree
Veronica
Wheat
Wisteria, Chinese

VERY RESISTANT

Apricot, Japanese
Apricot, purple
Avocado
Bean, soya, var. Laredo
Bean, velvet
Beggarweed, Florida
Berseem clover, Egyptian
Bermuda grass
Blue grass, annual
Blue grass, Kentucky
Cherry, sour
Cherry, sweet
Chokecherry
Chufa
Cineraria, silver
Clover, bur
Clover, Egyptian
Coreopsis, lance
Coriander
Cowpea, Suwanee
Cowpea, Victor
Cowpea, Virginia blackeye
Cowpea, K-890-3
Cowpea, 672
Crotalaria
Feijoa
Fescue grass, meadow
Fescue grass, sheep
Gaillardia
Gardenia
Grass, Bermuda
Grass, Johnson
Grass, Kentucky blue
Cowpea, Brabham, Iron Monetta
Grass, Natal, orchard, perennial rye
Jasmine, Spanish
Jujube, common
Juniper
Nectarine, vars. Quetta, Traveler
Oat, cultivated
Orange, hardy
Peach, Bokhara
Peach, Early Wheeler
Peach, P. I. 41395
Peach, Shalil
Peach, Yunnan
Pine, mature
Pistache
Plum, hortulan
Potato, sweet, vars. Goldskin, Porto Rico, Red Jersey, Southern Queen, Yellow Jersey

OTHER SUSCEPTIBLE SPECIES[11]

Alder
Alyssum, sweet
Anemone
Angelica
Ash
Balsam, garden
Barberry, European, warty
Bean, Adzuki, broad, common, kidney, rice
Begonia
Bellflower
Bird-of-paradise
Boysenberry
Broom, Scotch
Buckwheat
Butterfly bush
Bush clover shrub
Bush honeysuckle
Calabash
Caladium, spotted
Camomile
Canary palm
Cape jasmine
Capiscum, common red pepper
Cardinal flower
Cassia
Cattail, common
Cauliflower
Celery
Celosia
Chard
Chayota
Chickpea
Chicory
China aster
Chrysanthemum
Cleome
Clove pink
Cockscomb
Coleus
Columbine
Coontie (Zamia floridana)
Coraltree
Cornflower
Cypress spurge
Cypress vine
Daisy, English, oxeye
Dandelion
Dasheen
Dill
Dragon tree
Eggplant
Elephant's ear
Elm
Endive
Erythrina (coral tree)
Fennel, common
Fenugreek
Filbert
Forsythia
Foxglove
Freesia
Fuchsia
Gilia
Gourd
Grass pink
Ground cherry
Heliotrope
Hollyhock
Horseradish
Hyacinth bean
Iceplant
Impatiens
Joseph's coat
Lavender
Leek
Lentil
Lippia
Love-lies-bleeding
Madeira vine
Mallow
Maple
Marshmallow
Mignonette
Milkweed
Mock orange

[11]Degree of susceptibility uncertain, unless given in preceding columns.

Momordica	Nandina
Monk's shood vine	Nightshade
Moonflower	Olive
Morning glory	Oxalis

IMMUNE

Amaryllis	Guayule	Poppy, prickly
Azalea	Millet, Japanese, pearl	Teosinte
Citrus	Narcissus	Tulip
Grass, rescue		

LOSSES FROM ROOT KNOT

Losses from root knot cited by investigators vary from a trace to heavy. Although Bessey's statement[12] is very true that "The disease . . . has caused losses whose extent can not be calculated," still a few citations taken at random from numerous reports may serve to emphasize the importance of root knot. Cobb[13] estimates losses in the United States as amounting to several million dollars. Brown[14] says that "great areas of very valuable land in the Sacramento-San Joaquin delta are rendered unfit for the profitable production of potatoes, sugar beets, and other crops." Le Roux and Stofberg[15] report that "heavy losses are incurred as a result of this disease in tobacco, tomatoes, potatoes, peas, beans, cucurbits, flowers and various other crops." Ficht[16] finds that root knot decreased the income of tomato growers to the extent of $32 per acre, based upon a price of $12 per ton: he attributes to the disease a decrease of 45,546 per acre in the number of fruits set by the Marglobe variety. Middleton[17] observed a 40 per cent loss in potatoes severely infested with nematodes. Pinckard[18] estimates that the annual value of gardens in one southern state is lowered $1,100,000 by root knot. Annual losses in Ohio in vegetable greenhouses amount to more than $100,000, according to Newhall.[19] Kinkaid and Reeves report an average loss of 5 per cent in wrapper-leaf tobacco in Florida, with a maximum loss of 50 per cent.

Losses in Arizona from root-knot nematode are comparable to those in other regions having a similarly warm climate. King

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[12] Bessey, Ernst A., "Root knot and its control." *U.S.D.A. Bul. 217*, 1911.
[13] Cobb, N. A.
[14] Brown, Lloyd N., "Flooding to control root-knot nematodes." *Jour. Agr. Res. 47*: 883-88, 1933.
[15] Le Roux, J. C., and Stofberg, F. J., "Control of the root-knot nematode by cultural practices." *S. Afr. Dept. Agr. & For. Sci. Bul. 188*, 1939.
[16] Ficht, G. A., "Root-knot nematode of tomatoes in relation to the Indiana canning crop." *Ind. (Purdue) Agr. Exp. Sta. Bul. 434*, 1939.
[17] Middleton, John T., "Recent root knot damage in potatoes." *Pl. Dis. Report. Suppl. 124:* 145, 1940.
[18] Pinckard, J. A., "Root knot." *Miss. Agr. Exp. Sta. Circ. 104*, 1942.
[19] Newhall, A. G., "Control of root-knot nematode in greenhouses." *Ohio Agr. Exp. Sta. Bul. 451*, 1930.

Plate XII.—Root knot on chard.

and Hope[20] state that "the disease has become a problem in the production of cotton in parts of the Salt River Valley . . ." Gottlieb and Brown[21] found that root knot associated with southern sclerotial rot (caused by *Sclerotium rolfsii*) seriously affected approximately 600 acres of cotton in a block in the same Valley. There, most infested fields (Plate XI) produced about 50 per cent or less of normal crop, but one field observed was a total loss. Also recorded in this Department are numerous cases of damage from root knot involving sugar beets, tomatoes, cabbage, cantaloupes, watermelons, squash, sweet potato. Knotted plants from gardens and commercial plantings continually arrive for diagnosis in this laboratory from all parts of the state. Nor are the losses confined to garden and truck crops. Peach and fig orchards as well as vineyards have been damaged. For example, an entire harvest from a peach orchard in the Arivaipi Valley was sold below the market price because the fruits were smaller than peaches grown in healthy orchards and offered in the same market. Investigation disclosed a very severe infestation with the common nematode in the orchard concerned. To these losses must be added the damage inflicted upon shade trees, ornamental trees, shrubs and herbs, and even upon lawns of lippia and white clover. Such damages annually amount to a startling sum in an arid region where irrigation is necessary and where shade and ornamental plantings involve extra expense.

THE CAUSE OF ROOT KNOT

Root knot is caused by a microscopic roundworm or nematode that is also called eelworm because of its shape. The female averages about 1/30 inch long by 1/50 inch thick; the male, 1/21 to 3/50 inch long by 1/833 by 3/208 inch thick. Young worms called larvae feed along the surface and enter the tender parts of the underground organs of suitable food plants, particularly the growing region of the root of such plants. They increase in size, meanwhile feeding upon the plant juices. Within nineteen to thirty days, under favorable conditions, the young females begin to lay eggs. The male appears to be unnecessary for reproduction. Tyler[22] says "the occurrence of males is rare: only 0.7 per cent have been found in single-nematode cultures . . . Observations suggest that in the field also males occur under adverse conditions." Young worms (larvae) enter the tender parts of the underground organs of suitable food plants, particularly the growing region of the root. About sixty to seventy hours after the worm enters it, the root starts to make giant cells (Fig. 1), the beginning of a gall.

[20] King, C. J., and Hope, Claude. "Field practices affecting the control of cotton root knot in Arizona." *U.S.D.A. Circ. 337*, 1934.

[21] Gottlieb, Manfred, and Brown, J. G., "Sclerotium rolfsii on cotton in Arizona." *Phytopathology 31*: 944-46, 1941.

[22] Tyler, Jocelyn, "Reproduction without males in aseptic cultures of the root-knot nematode." *Hilgardia* 7: 373-88, 1933.

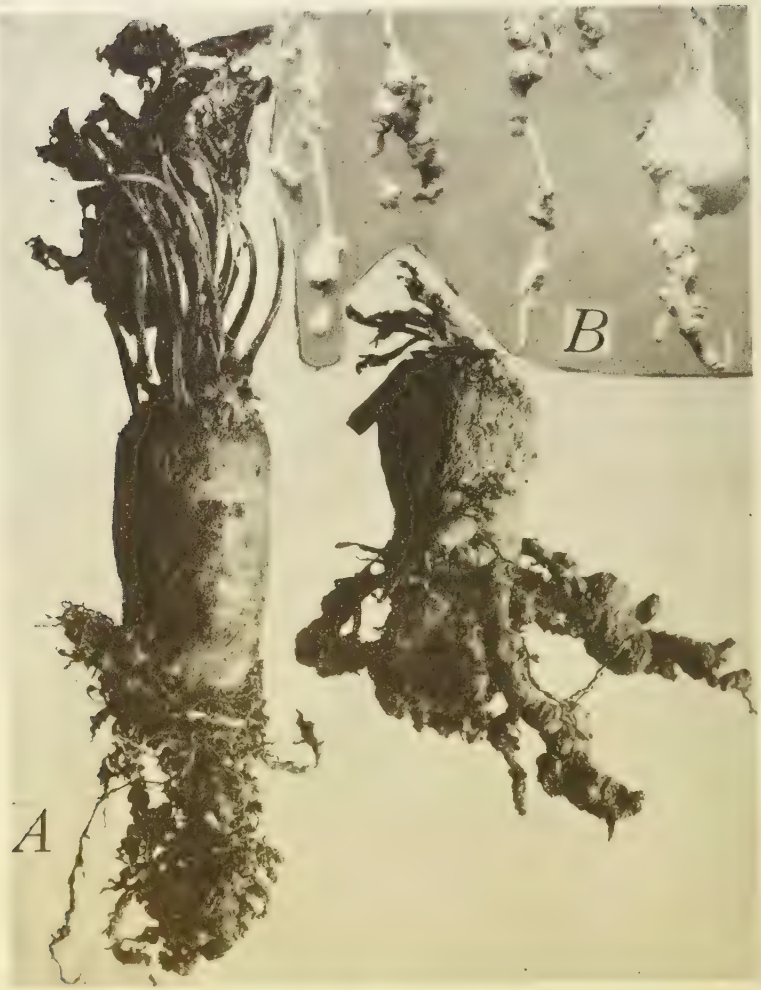

Plate XIII.—Root knot on sugar beet caused by the common nematode; (A) dwarfed plants; (B) "close-up" of a few separate and clustered knots.

Within the gall the mature females lay numerous eggs in masses that are surrounded with a mucus substance. The egg masses may rest inside the gall or become pushed to the surface. The egg itself is covered with a chitinous substance that is highly resistant to soil disinfestants. Another important fact in connection with infestation of the soil is the large number of eggs that can be produced by one female. A single female can lay ten to fifteen

Plate XIV.—Celery plants first diseased with root knot and afterward with vegetable soft rot caused by a bacterium, *Erwinia carotovora*. Either disease, alone, may cause death of the plant; when the two are associated, destruction quickly results.

eggs per day until a total of 600 to 1,200 or more eggs have been deposited.

Eggs that are pushed to the surface of the gall begin to hatch at once if conditions are favorable, and soon the larvae from them are seeking new roots. Eggs laid within the gall may hatch there and their larvae migrate to other parts of the same root or pass out into the soil. Larvae may live for several months in the soil without taking in food.

Several characteristics of the life-cycle of the root-knot nematode are particularly important in connection with the combating of infestation. The large numbers of eggs produced per female means rapid spread of infestation, particularly in warm, irrigated regions. Not only the numerous eggs and worms but also parts of knotted roots and fragments of galls may become widely distributed by irrigation water in a short time. Since no fertilization is necessary, there is small chance for a slowing of the rate of increase in nematode population of the soil through lack of development of the eggs. Limitation of infestation to the underground parts of plants means that propagation by seeds and aerial cuttings is safe; the root-knot parasite can be introduced into clean soil, so far as plant parts are concerned, only by infested subterranean organs such as roots, tubers, corms, and bulbs.

HOW TO AVOID ROOT KNOT

That the cause of root knot, the common nematode, is not native to Arizona[23] has already been hinted, but that fact cannot be overemphasized. The parasite does not exist in virgin soils that have not been reached by irrigation water from infested cultivated land. Root knot is so serious and the cost of its eradication is so great that every effort within reason should be exerted by operators of noninfested farms and owners of clean home lots to prevent the introduction of its cause.

Since root knot is most commonly introduced on stock from infested nurseries, no rooted plant of any susceptible kind obtained from that source should be planted without careful inspection of the roots for knots. During the inspection particles of soil must not be dropped from the roots to the ground, for eggs and nematodes may thus start infestation. Particular attention should be given to plants with balled roots and plants in pots, cans, or other container. Stock with knots, large or small, excepting pod-bearing plants, should be refused or destroyed. Pod-bearing plants (legumes) with knots only on the side of the rootlet (Plate VI) do not have root knot, but those with knots IN the roots should be rejected.

Root knot or other dangerous or troublesome malady is frequently present on nursery stock offered in sales at reduced prices. In general, such sales are to be avoided unless the nursery concerned is known to have a reputation for clean stock. Even then,

[23] Bessey, Ernst A., "Root knot and its control." *U.S.D.A. B.P.I. Bul. 217*, 1911.

Plate XV.—Root knot on main and lateral roots of cantaloupe plant.

Plate XVI.—(A) Fruitless mulberry trees with wilting leaves, although they are standing in irrigation basins nearly filled with water. Infestation had proceeded from a diseased tree in background through water in irrigation ditch. (B) Knotted roots taken from tree on right.

all rooted plants from nurseries should be examined for root knot before they are accepted. Especially watched should be out-of-state nurseries that advertise, by radio, bargain lots of plants. Purchasers of "trees" from that source have sometimes received seedlings only a few inches in length that require several years to reach the size of locally available stock, and, besides, have risked the introduction of root knot and other serious diseases.

The root-knot nematode may be introduced into a clean field through the medium of soil adhering to farm implements and tools. Before tractors, plows, cultivators, hoes, shovels and other implements and tools that have been employed in infested soil are used in clean soil, they should be thoroughly cleaned and disinfested with formaldehyde or other strong disinfestant. Liquid disinfestants are most readily applied to machinery and implements by spraying after thorough cleaning. Tools may likewise be cleaned and sprayed or dipped in disinfestant. For use in dipping hoes, spades, rakes and like tools, a five-gallon can or bucket with tight cover, containing 5 per cent formaldehyde solution, is handy. The solution can be repeatedly used if kept tightly covered to prevent evaporation of the chemical.

Root knot is frequently brought to clean soil with exchange or gift plants. All rooted plants received in that way should be carefully examined for knots. Potted plants found to be infested should not be discarded where infestation of soil may occur, but the pot and its contents should be boiled or otherwise disinfested before the container is emptied.

Root-knot infestation may result from the discarding of parings from infested potato tubers, carrots and other vegetables as well as from entire tubers, roots and other infested parts. Particularly should waste of that kind be kept from contaminating manure in which nematodes may quickly be distributed over fields. Before feeding vegetable waste to hogs or other animals it should be boiled if it is suspected to carry the root-knot nematode.

Nematode distribution by wind-blown soil seems unlikely, considering (a) the shunning of dry soil by the roundworms, and (b) the killing effect of drying. However, it appears possible that, in rare instances perhaps, small knots not yet sufficiently dried to kill nematode eggs, might be carried a short distance by our "twisters" that are so common in summer in the Southwest. No suspected case of wind-dissemination of the root-knot nematode is known to the writer.

TEST OF THE SOIL FOR THE ROOT-KNOT NEMATODE

Preliminary test of soil for the presence of the root-knot nematode may save loss of the crop and, more important still, infestation of permanent plantings. The discovery of infestation when only a small area of soil is affected makes possible cheap eradication whereas, if eradicative measures are postponed, the infested area may be quickly enlarged by irrigation and in other ways, and the cost of eradication vastly increased.

Plate XVII.—The weeping willow (*Salix babylonica*) is often killed by root knot. Note the leafless, whiplike branches from which the yellowed and dried leaves have fallen. Many dead leaves still cling to the tree.

Test of the soil for the common nematode is simple; it may be made either in the area to be planted or in soil-sample containers. Where soil in place in a garden or other small area is to be tested, seeds of nematode-susceptible plants (Pages 16, 18) are set, two or three in a spot, spaced 3 or 4 feet apart, in the area to be tested. When the resulting seedlings have developed a root system, specimens of the plants are removed here and there, at intervals of seven to ten days and their roots are examined for galls. By making use of pots or cans, soil to be planted in spring may be tested in the same way during the winter previous to planting, provided that a warm room is available in which the test plants can be grown. In that case, the soil samples should be taken at a depth of 2-6 inches from numerous locations in the area under test in order to make them representative. Each location and corresponding sample should be marked. The soil in the containers is then planted with seeds of squash, cantaloupe, or other susceptible species, and the roots of the resulting seedlings are examined as previously described. Containers found to hold nematode-infested soil, as well as the corresponding infested areas, should be disinfested (Pages 33-38). Test of large areas is best made by planting a nematode-susceptible crop (Pages 16, 18). The suggestion is here offered that classes in agriculture in high schools, and even youngsters in country and grade schools, can soon learn to make tests of soil for the root-knot nematode and thus make valuable nematode surveys in their home districts.

DISINFESTATION OF NEMATODE-INFESTED SOIL

Nematode-infested soil can not be disinfested without killing the affected plants growing in it. Agencies used for killing nematodes and their eggs in the soil are heat and chemicals.

HEAT

Heat may be applied to the soil either in dry or moist form. Dry heat was earliest used in the practice of burning brush, straw, or other combustible material scattered over the soil surface. Although that practice may kill weed seeds, fungi and bacteria on or near the surface, it is ineffective against nematodes. However, dry heat can be used to disinfest small quantities of nematode-infested soil. The soil in small pots or other container is baked in an ordinary oven until a potato tuber, buried deeply in the soil of the largest container, is well cooked. Dry heat may also be applied to larger quantities of soil by using an electric oven. Forms of electric ovens adapted to the requirements of small nurseries and gardens may be homemade or purchased[21] ready for use. The electric oven is essentially a heat-insulated box provided with heating coils, hinged top for loading and hinged bottom for unloading. However dry heat is applied to soil to quickly

[21] The Consolidated Car-Heating Company, Inc., Albany, New York, advertises an electric soil sterilizer of 1 cubic yard capacity.

Plate XVIII.—Large nematode galls on Kitchingia tree (*Kalanchoe beharensis*).

destroy nematode eggs, there is the disadvantage that it will damage or destroy organic matter.

Moist heat used to disinfest soil is usually applied in the form of steam. For disinfesting soil in place in small plats and seedbeds, the inverted pan is sometimes used. The pan (Plate XIX) is a galvanized iron box commonly 6 ft. by 10 ft. by 6 in. deep. The edges of the open side are sharp so that the inverted pan can be forced into the soil to prevent the escape of steam. The apparatus is provided with steam-hose connections and fitted with handles to facilitate carrying it from place to place. The weight of the pan is approximately 400 pounds. After the pan is in position over an area to be disinfested, steam generated in a portable boiler, traction engine, or other suitable apparatus, is admitted to the pan through the steam hose. A pressure of 80-150 pounds kills nematodes and their eggs, soil fungi and bacteria, and weed seeds in about one hour.

For steaming greenhouse benches, perforated pipes or tile may be permanently placed close enough together under the soil so that the steam issuing from them will reach every part of the bench. Steam from a central plant may then be instantly available by the opening of a valve. That method of disinfestation involves a considerable outlay for equipment and is better adapted for use in a climate cold enough to necessitate the operation of a strong heating plant rather than for use in a mild climate such as ours.

Disinfestation of soil in a truck body, by steam, may be accomplished through the use of a grid (Plate XX) that may be constructed of gas or water pipe. The pipes are drilled with numerous small holes for the exit of steam. Holes drilled on the under side of the pipes rarely become clogged with soil. The grid, made to fit the steel body of the truck, is placed in the latter and the soil shoveled upon it until the truck is filled. The soil is then covered with a tarpaulin, canvas, old blankets, or other available material; steam is admitted to the grid through a valve in the outer end. At 40 pounds pressure, a temperature of 200 degrees F. or higher may be obtained at the top of the soil mass. With the grid we have used a minimum period of two hours for steaming after the maximum temperature was reached. Laboratory cultures then made showed that the soil was sterile. We use waste steam from the power plant to operate the grid in winter. Steam treatment in the truck requires no extra labor expense in handling the soil.

The horizontal steamer used by canners is another type of apparatus that is handy and efficient for disinfesting soil with steam. It is inexpensive. We have used for several years such an apparatus.[25] The steamer is adapted to the requirements of small nurseries and flower gardens in disinfesting soil for benches and pots.

[25] Manufactured by the Sprague-Sells Corporation, Hoopeston, Illinois.

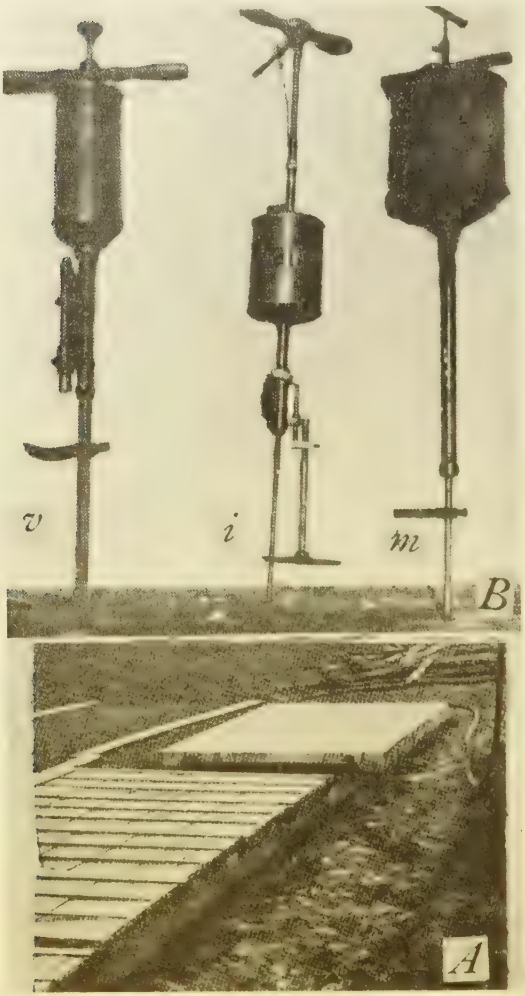

Plate XIX.—Means for applying disinfestants to soil: (A) inverted pan for steaming soil; hose connection at left. (Modified fr. Steven and Hall: *Diseases of Economic Plants*, Rev. Ed. copyright, 1910 and 1921 by the Macmillan Company and used with their permission.) (B) soil injectors for applying fumigants: (v) Vermoral Pal (P.E. Lirio, Vineland, N.J.); (i) Isco Larvajector (Innis Speiden Co., 117 Liberty St., N.Y.); (m) Mack Anti-weed Gun (Wheeler, Reynolds and Stauffer, San Francisco).

Plate XX.—Grid for steaming soil in the body of a truck, made of perforated gas pipe. Vertical pipe at end of grid is connection for steam supply. Designed by Dr. R. B. Streets.

Heat applied in the form of boiling water may be used in the home for killing nematodes in the soil of pots and other small containers. The containers with their soil are placed on wooden slats in a common wash boiler which is then filled with water to a height just above the tops of the containers. Boiling is continued until a potato tuber deeply buried in the soil of the largest container is thoroughly cooked. The containers are then removed to a clean surface to drain and cool. This method of disinfestation removes from the soil valuable compounds that otherwise might be used for plant growth; "puddling" of the soil may also be an undesirable result.

CHEMICALS

Only a few of the numerous chemicals tried for control of the common nematode can here be considered. In general, chemical disinfesting of the soil has been commonly regarded as too expensive for large areas but now that practice is coming in with decreasing cost of fumigants and availability of machines for application. Some chemicals adapted for use on infested plats, in greenhouses, and for disinfesting soil in containers are chloropicrin, carbon disulphide, DD mixture, ethylene dichloride, formaldehyde, and methyl bromide.

Chloropicrin, also called tear gas and sold under the trade name of Larvacide,[26] is probably the best all around soil fumigant[27]

[26] and [27] See next page.

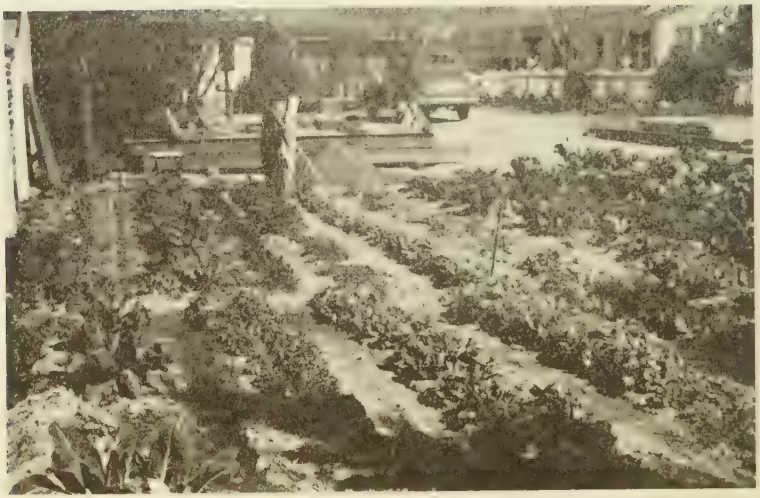

Plate XXI.—This thrifty backyard garden is growing in soil in which the previous planting was seriously damaged by root knot. This planting was preceded by soil treatment with DD mixture, $2\frac{1}{2}$ ml. 6 inches deep and 10 inches apart, in rows 12 inches apart. Treatment is inexpensive and might well be adopted as a rule to follow every year before planting the garden.

available on the market at present. It kills not only nematodes but also moist weed seeds, fungi, and bacteria in the soil. With it soil may be disinfested in place or after removal to benches, pots, flats, bins or other container. Soil in place in garden plats (Plate XXI) and seedbeds is first spaded or otherwise tilled, then raked to break lumps and remove galled roots. Fertilizer and amendments such as barnyard manure should be added. The soil should be neither wet nor dry but medium in moisture content; in the proper tilth for treatment, it will just fail to hold its shape when it is squeezed in the hand and pressure then released. The soil temperature should be at 65 degrees F. or above for best results.

When the area to be treated is properly prepared and temperature and moisture are right, the plat is marked in 10- or 12-inch squares. Injections of chloropicrin are made at the corners of the squares. Although good results have been reported from the use of smaller injections and larger spacings, under favorable conditions, we believe that a dosage of 2.5 cc. with 10-inch spacing is best for most of our soils. Advisable depth of injections, usually

[26] Manufactured by Innis, Speiden & Company, 117-119 Liberty Street, N.Y.; Western Agency, California Biological Service, Glenoaks Boulevard, Glendale, California.

[27] Newhall, A. G. and Stark, F. L., Jr., "Chloropicrin and ethylene dichloride for root-knot nematode control." *Phytopath. 32*: 626-30, 1942.

Plate XXII.—Treatment of the soil to kill the root-knot nematode must be carefully done. The cucumber plant that produced the heavily knotted roots here illustrated was grown in a nematocide-treated soil.

6 inches for garden soil, will be deeper for soil that has been in contact with deep-rooted plants.

Injections of chloropicrin into the soil are most conveniently made by using a soil "gun" (Plate XIX) such as that sold by the manufacturers of Larvacide under the name of Larvajector. However, the chemical diluted with gasolene 1:3, can be dropped in accurate dosage into holes previously made in the soil by using a large, calibrated syringe. The soil-holes may be made with a peg-shaped stick thrust through an opening in a wooden disk, piece of old automobile casing, or other stiff material used to regulate the depth of the holes. Immediately after injection, the holes in the soil are filled and made firm by stepping upon them. As soon as a plat is treated, it is either covered (with wet canvas, gunny sacks, building paper, or even old newspapers) or wetted to the depth of an inch or two in order to confine the volatile chloropicrin to the soil. Covering or wetting should continue for three days. If surface wetting is employed, frequent sprinkling will be necessary in our dry air. When the covering is removed or the soil surface is allowed to dry, the chloropicrin evaporates; in ten days thereafter planting is usually safe.

Chloropicrin may be used for disinfesting potting soil in containers. The screened soil, after the addition of manure, is placed in a tight barrel, in a layer 6 inches deep. The layer is then sprinkled with 1 ounce (30 cc.) of Larvacide. A second layer 1 foot thick is added and sprinkled with another ounce of the fumigant, and the process of adding soil and sprinkling is continued until the container is filled. A tight-fitting cover is applied and the soil left for three days. Then, after aerating, it may be removed to clean containers and planted. Chloropicrin may be applied to soil in flats in a dosage of 2 cc. injected half way to the bottom at four equally spaced places. The flats are then stacked and the surface of the top flat is covered with wet canvas or other material as previously described for soil in place.

Although chloropicrin is not considered to be lethal it is annoying, particularly to the eyes and respiratory organs. The fumes should not be breathed. The fumigant should be handled in the open air. In filling the larvajector or otherwise handling chloropicrin, the operator should stand on the windward side of the container so the fumes will drift away rather than toward the worker.

Carbon disulphide has been used successfully in the control of the root-knot nematode, usually at the rate of 1,000 to 3,000 pounds per acre, or approximately 23 to 68 pounds per 1,000 acre-feet The chemical may be applied to the soil in the same manner described for chloropicrin. This fumigant is less destructive to weeds and certain soil-dwelling fungi than chloropicrin. It is also explosive in nature and must be handled with caution.

DD Mixture (dichloropropane plus dichloropropylene), although comparatively new, has been tried in various locations through the country for the control of the common nematode. It

kills the parasite but we have found it less effective against fungi and weed seeds in the soil. DD mixture is comparatively safe to handle although the fumes are unpleasant; another advantage is its nematocidal action in soil as cool as 30-40 degrees F. It is used much like chloropicrin. Two to three weeks should elapse between treatment and planting of the soil.

Ethylene dichloride at the rate of 1,000 to 2,000 pounds per acre kills the root-knot nematode but is less efficient than chloropicrin against weeds. It is noninflammable but combustible, much like kerosene. It is used in like manner to chloropicrin.

Methyl bromide is very effective in killing the common nematode, even in the small dosage of 1 milliter per square foot or about 167 pounds per acre. The chemical changes from liquid to gas at less than 5 degrees C., therefore requires a special applicator. Application to the soil is made under a gas-tight cover. A gas mask should be worn by workers with the chemical who operate indoors.

Formaldehyde solution of proper strength has been successfully used for disinfesting nematode-infested soil in containers. Before the application of the solution to the soil the larger roots and galls, if present, should be screened out. A concentration of 5 per cent formaldehyde should be used in order to kill nematode eggs that may be present. In preparing the solution the strong (37 per cent) commercial formaldehyde is considered as 100 per cent.

Spot Treatment. By spot treatment is meant the application of the disinfestant only to the area to be actually occupied by the roots of the growing plant. Spot treatment therefore costs less than complete coverage of a field. The method can be used for crops planted in hills and rows that are far enough apart. It is adaptable to the use of different fumigants.

An example of spot treatment cited by Taylor[28] was the treatment of a field later planted to watermelons. After preparation of the soil and marking the location of the hills, chloropicrin at a dosage of 1-2 ml. was applied directly under the planting spots and an area of approximately 1 square yard was sprinkled with water. A week later planting was carried out. At harvest less than 3 per cent of the hills was lightly infested. The cost of the spot treatment was about $5 per acre for the nematocide and $3 to $5 for the cost of application, with hills 8 feet apart.

The spot method does not eradicate nematodes but merely gives the concerned crop a start before infestation occurs. Irrigation by flooding probably would detract from the benefit otherwise derived from spot treatment; also the continued wetting of the soil surface of the treated spots, even for a few hours in Arizona's dry air, presents a problem.

[28] Taylor, A. L., "Chemical control of root knot." *Root-Knot Nematode Conference Rept.*, Feb. 4-6, 1941.

Fumigation of large areas of soil (Plate I) appears to be coming in as a farm practice, particularly in connection with the growing of special crops that promise large financial returns. For disinfesting fields machines are available on the market but they are more or less expensive. Recently King and Andison[29] have described a simple applicator that can be constructed "on the farm or in a garage at a cost of ten to fifteen dollars for parts." The applicator is a tank placed on the top of a tractor-drawn plow from which a tube delivers the liquid fumigant at the bottom of the open furrow in front of the plowshare.

LIVING WITH NEMATODES

Farmers, truckers and gardeners who cannot attempt the chemical eradication of the common nematode on account of the cost, because of infested permanent plantings of trees and shrubs, or for other reasons, necessarily have to get along with the parasite as best they can. That means living with the nematode.

Some years ago just that situation was presented to the writer for solution. A small farm was so badly infested with the common nematode that no susceptible paying crop could be successfully grown on it. The cost of chemical eradication of the parasite seemed prohibitive to the owner. With the co-operation of the County Agricultural Agent (Mr. E. S. Turville), a program for planting was outlined. The program was based upon the use of resistant crops such as resistant cowpeas and corn, and the plowing under of green manure crops. For four years the owner of the farm grew the resistant crops in summer and seeded the infested land to rye in the fall, the latter crop being plowed under in the spring. By that program the owner so reduced the nematode population that tomatoes and other susceptible crops were grown for some years with no sign of injury. However, the parasite finally again appeared, showing that eradication cannot be expected as a result of such cultural practice, in agreement with a mass of literature on the subject.

Clean cultivation (removal of all weeds) usually helps to control the common nematode, particularly when combined with the growing of nematode-resistant crops. Results gained by that kind of practice are compared by Le Roux and Stofberg.[30] One set of plots was regularly hoed every two weeks; another set was plowed and weeded at monthly intervals with the object of starving the nematodes by the removal of susceptible plants. A third set of plots was planted with the resistant crops, oats in winter and sunnhemp (*Crotalaria juncea*) in summer. The investigators found that "nematode infestations can be effectively checked by starvation, i.e., through the elimination of all host

[29] King, K. M., and Andison, H. A., "A simple plow-equipment for applying liquid fumigants to the soil." *Div. Entomol. Processed Publ. No. 68* (Ottawa, Canada), March, 1947.

[30] LeRoux, J. C., and Stofberg, F. J., "Control of the root-knot nematode by cultural practices." *Union of South Africa Sci. Bul. 188*, 1939.

plants by regular plowing and hoeing, or the planting of resistant crops" but, "following commercial control of the nematode, only one susceptible 'annual' crop can, with safety, be grown to maturity." They also state that clean cultivation for nine and twelve months gave better control than the six months' summer or winter treatments.

Trap crops were once believed to afford the possibility of eradication of the common nematode. A trap crop consists of some very nematode-susceptible plant that is more attractive to the parasite than the crop to be protected. In practice, the trap crop is preferably planted around small units of the crop to be safeguarded, for example, a row of cabbage or cantaloupes around a bed of kidney beans. When the roots of the trap crop are strongly galled and therefore contain a large number of nematodes (also eggs), the plants are removed and the roots destroyed; the practice may then be repeated. Plants of the trap crop must be removed before their galls liberate a new lot of nematodes into the soil. The use of a trap crop may only reduce the nematode population but does not eradicate the parasite.

Flooding with water has been tried as a means for reducing the nematode population of infested areas. Flooding for short periods of time, even with salt water[31] is ineffective. Submergence of infested soil for 22.5 months, but not for a shorter time, in Cali-

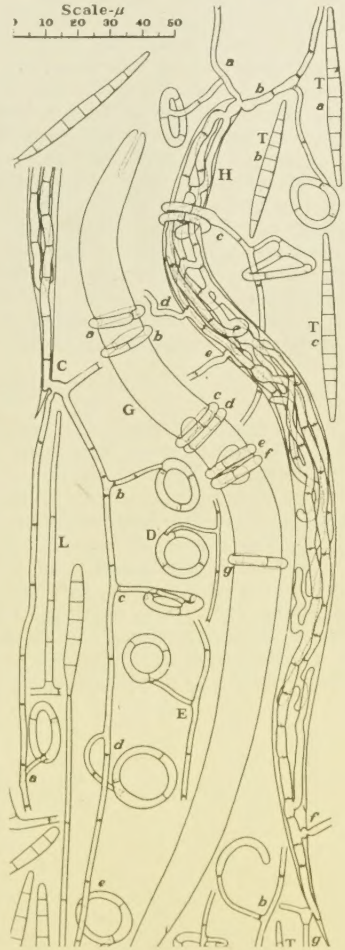

Figure 2.—A nematode-catching and killing fungus (*Dactylella leptospora*). The fungus threads (hyphae) form many rings or loops, A-F, that catch nematodes; then branching threads grown through the body of the nematode, absorb its contents and kill it in that way, Figs. G and H.
(Modified from Drechsler)

[31] Watson, J. R., and Goff, C. C., "Control of root knot in Florida." *Fla. Agr. Exp. Sta. Bull. 311*, July, 1937.

fornia, killed the common nematode.[32] Loss of the use of land for long periods and, in most cases, the scarcity of irrigation water make flooding impractical for use in Arizona.

Those who must live with the common nematode usually find a combination of the practices previously mentioned, excepting flooding, to be effective. Soil fertilization with barnyard manure (to take the place of leaf mold) and the plowing under of green manure crops favor the growth of a rich fungus flora. Among the fungi there may be numerous kinds that catch and kill nematodes (Fig. 2). For green manure, barley is probably as useful as rye and more commonly grown than the latter. Lawn clippings can thus be used on the soil under infested shade and fruit trees on home lots. The growing of grass rather than lippia, dichondra, or other susceptible plants between trees is a help in preventing the spread of root knot. Individual watering of trees and shrubs rather than ditch irrigation from one plant to another constitutes a preventive factor.

SUMMARY

Root knot caused by the common nematode, (*Heterodera marioni* (Cornu) Goodey, a menace to agriculture, is rapidly spreading in Arizona. There is no cure for root knot.

The disease can affect approximately 1,300 different kinds of plants, including important garden, truck, orchard and field crops as well as many ornamentals, shade plants, and weeds.

The cause is not native to Arizona. It is commonly introduced on rooted plants from infested nurseries; the plants range from herbaceous tomato, cabbage and many other seedlings to fruit trees, shade trees and ornamentals.

Descriptions of the parasite, root knots that it causes, means for its control and eradication, and related topics are included.

[32] Brown, Floyd N., "Flooding to control root-knot nematodes." *Jour. Agr. Res.* 47: 11:883-88, 1933.